



# Pathogen: Using Campaign Intent To Guide Onboard Planning for a Self-Reliant Rover

Joseph A. Russino, Daniel Gaines, Steve Schaffer, and Vincent Wong

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**Jet Propulsion Laboratory**  
California Institute of Technology

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# Outline

- Introduction
  - Self-Reliant Rovers
  - Campaign Intent
- Problem Definition
- Pathogen: Using Campaign Intent to Guide Planning
- Evaluations
  - Onboard Planning Evaluation
  - System Evaluation: Mars Yard Walkabout Campaign
- Demonstration Video



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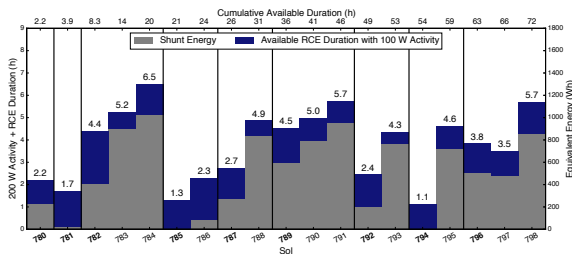
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# Introduction

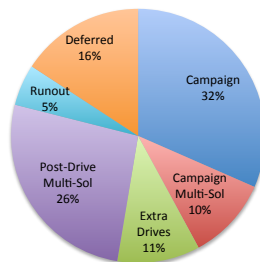
## Motivation – MSL Case Study

- Large percentage of sols not making significant contributions to campaign
  - 48% low productivity sols
- Significant amount of unused vehicle resources



**Pahrump Hills Estimate of Extra Available Duration**

### Pahrump Hills



- Opportunity exists to increase productivity
  - Sols within campaign not providing significant contribution to objectives
  - Unused vehicle resources
- Significant challenges to overcome
  - Predicting available vehicle resources
    - Can unnecessarily limit activity
  - Ground-in-the-loop requirements for target selection and effective drive planning
    - Ground unable to productively fill “restricted” sols following drives
  - Ground-in-the-loop requirements to respond to outcome of activity
    - E.g. drive faults



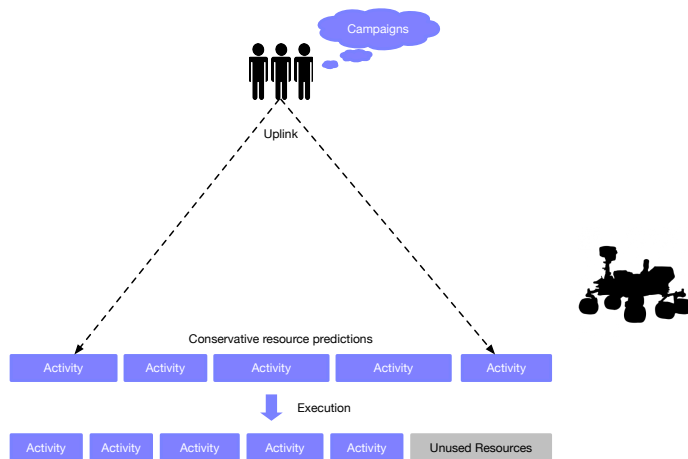
# Campaign Intent for Operator Guidance

## Challenge:

- Enable operators to guide rover without detailed knowledge of vehicle state

## Approach:

- Leverage concepts from rover operations
- **Campaign Intent:**  
Express higher level strategic guidance
  - Specifies relationships among objectives
  - Directs use of autonomous science



## Current operations

- Detailed planning on the ground
- Conservative resource allocations to avoid over-subscription
- No onboard knowledge of relationships among activities
- Results in unused vehicle resources

# Campaign Intent for Operator Guidance

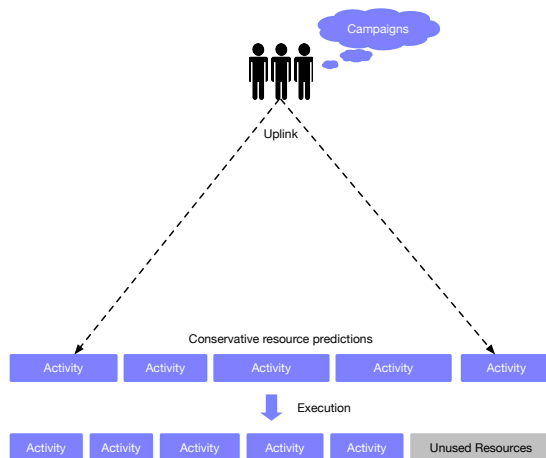
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- Enable operators to guide rover without detailed knowledge of vehicle state

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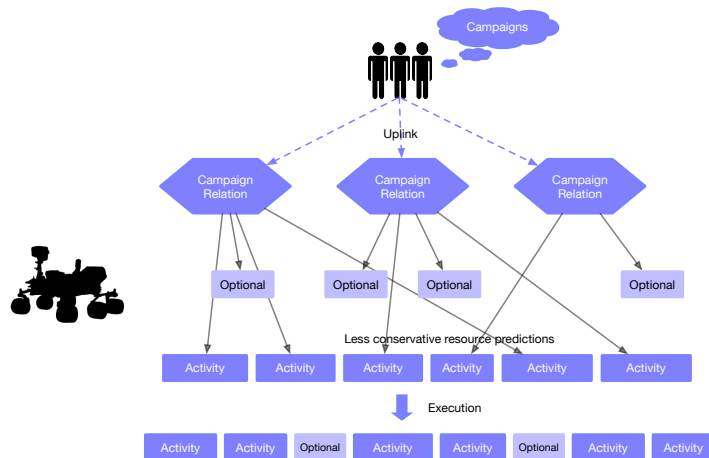
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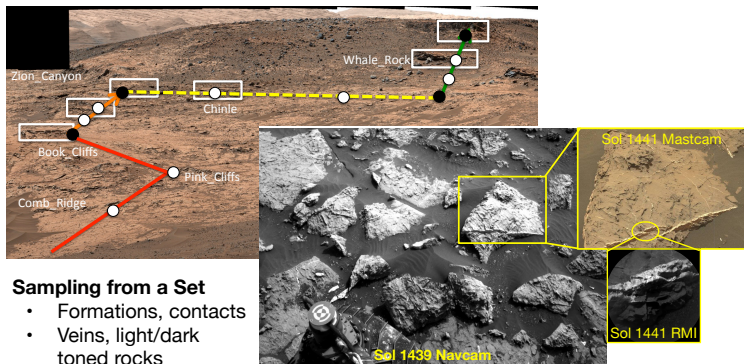


## SRR approach

- Onboard planning, resource management
- Less conservative modeling, over-subscribe vehicle
- Campaign intent expresses relations among activities
- Results in increased resource use

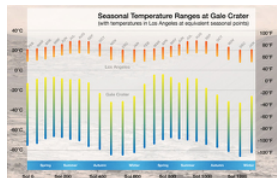


# Campaign Intent



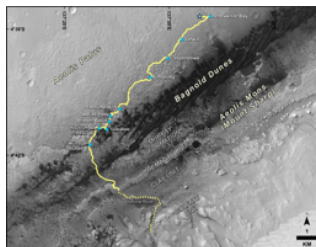
## Sampling from a Set

- Formations, contacts
- Veins, light/dark toned rocks
- Textures, layers



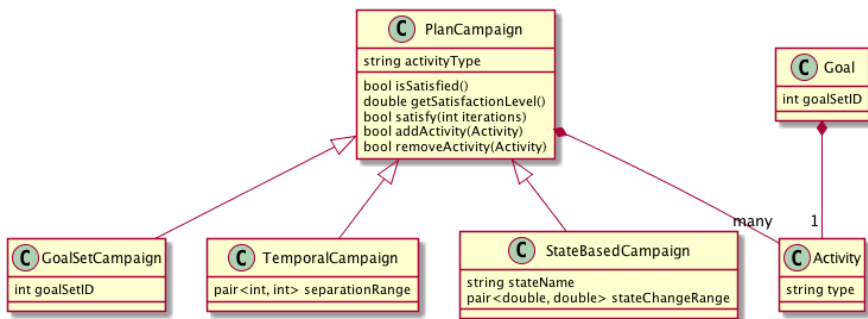
## Temporally-Periodic Sampling

- Across diurnal cycle
- Over seasons
- Periodic vehicle maintenance



## State-Based Sampling

- Drilling at varying elevations
- Surveys over rover traverse



- **Goal Set Campaign**
  - Activities scheduled from a defined group
  - Value is a function of number achieved within group
- **Temporal Campaign**
  - Activities scheduled based on temporal separation preferences
  - Value is a function on compliance with requested cadence
- **State-Based Campaign**
  - Activities scheduled based on state-change separation preferences
  - Value is a function on compliance with requested separation



# Problem Definition

- Inputs:
  - Goals
    - Priority, Utility
  - Campaigns
  - Exogenous Activities
  - Constraints
- Outputs:
  - Sequence of activities
- Goals:
  - Maximize utility
  - Comply with engineering constraints
  - Execute in real-time on rover hardware
  - Provide best plan available within allotted time (anytime)





# Pathogen: Using Campaign Intent To Guide Planning Algorithm

```
Result: Valid plan
Generate seed nodes
while ! Done do
    | Pick best pending node
    | Expand that node
    | Update pending nodes
end
Pick best pending node
```



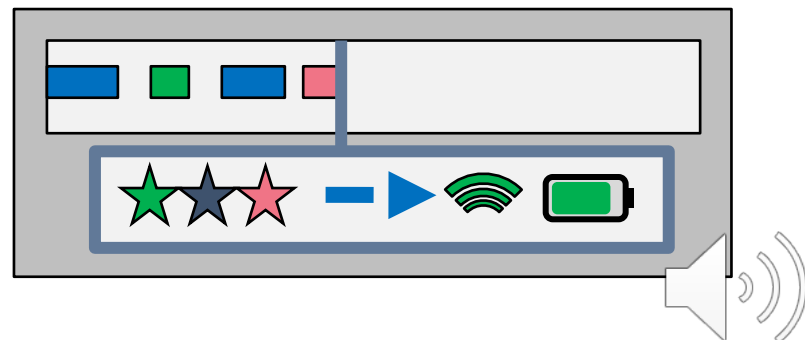
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# Pathogen: Using Campaign Intent To Guide Planning

## Seed Nodes

- Action Plan
  - Drives, goals, comms, sleeps, preheats, ...
- Forward sweeping “current” state
  - Time, location, resources
  - In-progress drives / interrupts
  - Campaign, goal statuses
  - Heating state

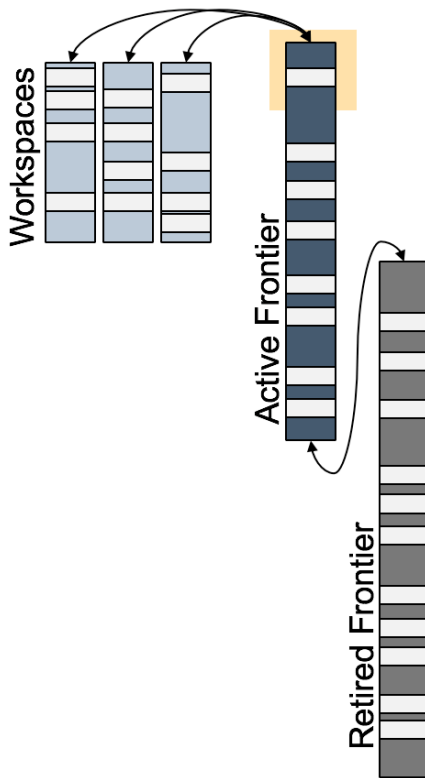
- Scores
  - Past utility + heuristic future utility
    - Aggregated from all goals
  - Organized by strict priority
  - Conflicts weighted negative



# Pathogen: Using Campaign Intent To Guide Planning

## Node Expansion

- Per-thread workspace frontier
  - Grows in depth-first bursts
  - Merged back to main frontier
- Active frontier repository
  - Sorted by heuristic value
  - Threads check out / merge work
  - Limited size for efficiency
- Retired frontier nodes
  - Collects least-promising nodes
  - Called back to active frontier as needed



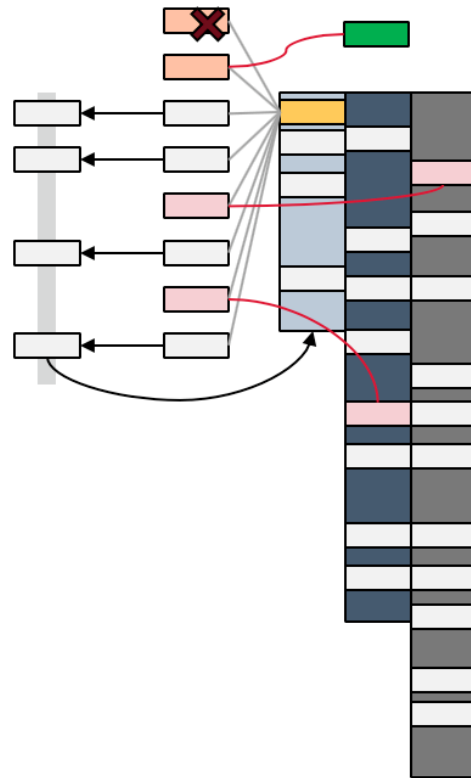
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# Pathogen: Using Campaign Intent To Guide Planning

## Successor Generation

- Check if prunable
  - Conflicts
  - Max can't beat best node
- Create successor nodes
- Score them
- Prune any poor children
- De-duplicate versus examined nodes
  - Uses hash function on plan
- Update best node metrics
- Push into workspace / frontier

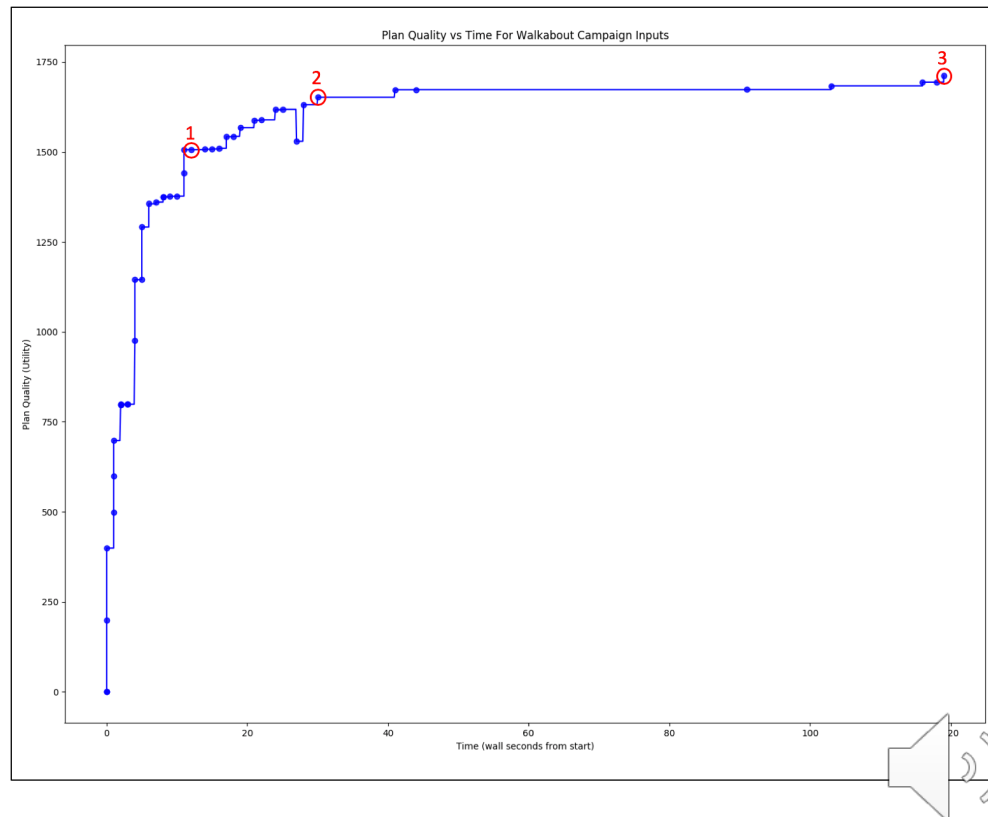


```
Result: Valid plan
Generate seed nodes
while ! Done do
  Pick best pending node
  Expand that node
  Update pending nodes
end
Pick best pending node
```

# Onboard Planning Evaluation

## Plan quality

- Generate acceptable plans quickly
- Take full advantage of time available for planning
- Return highest-quality plan possible for a given amount of planning time

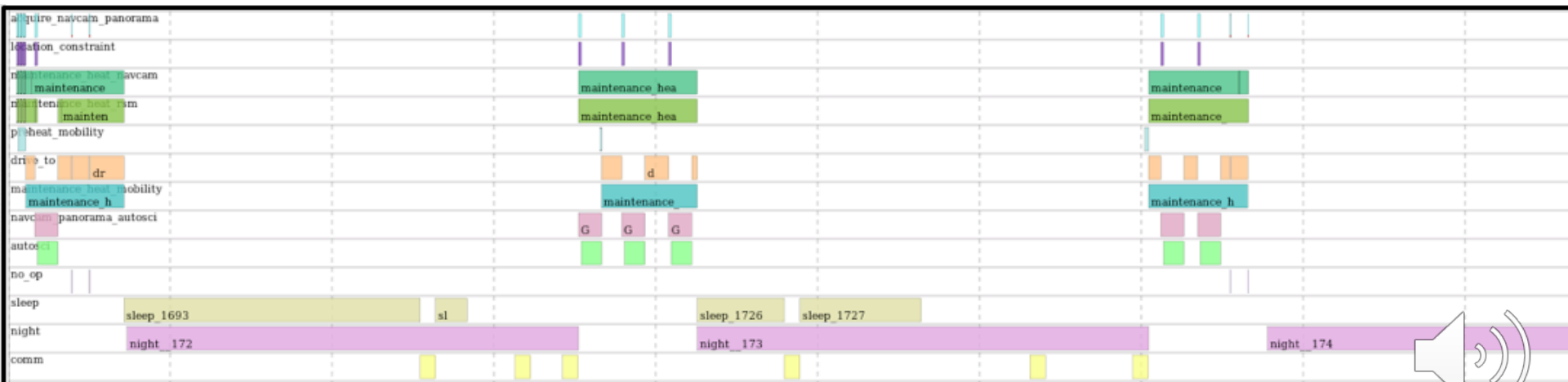
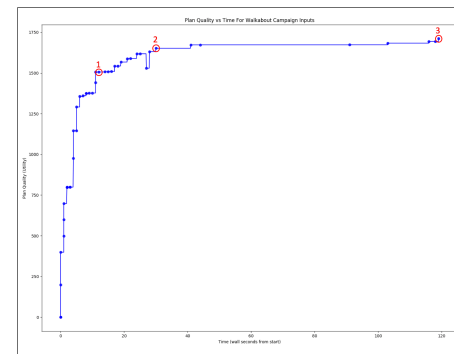




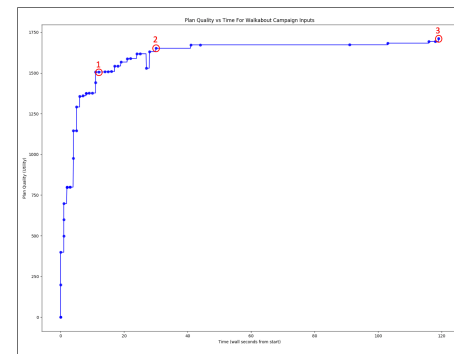


# Onboard Planning Evaluation

- Early iterations only accomplish a subset of the goals

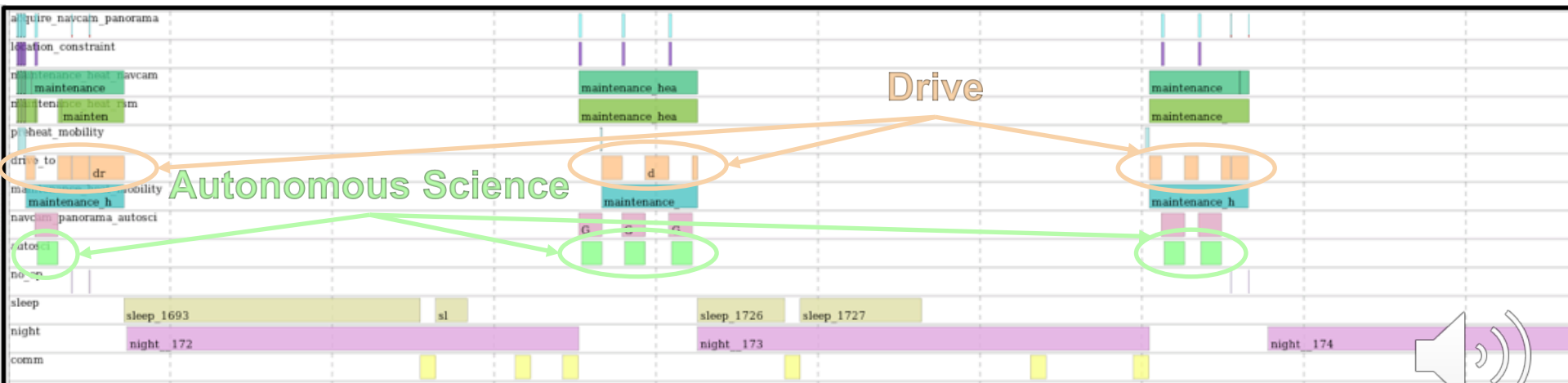
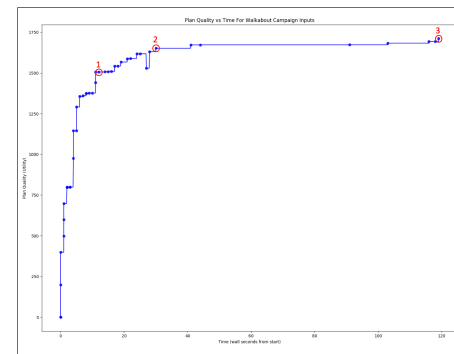


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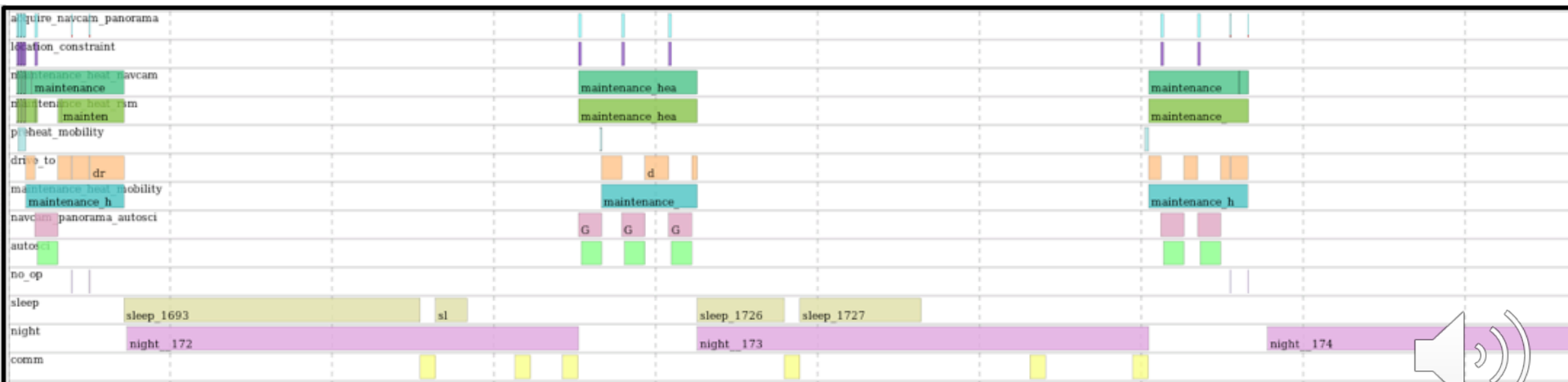
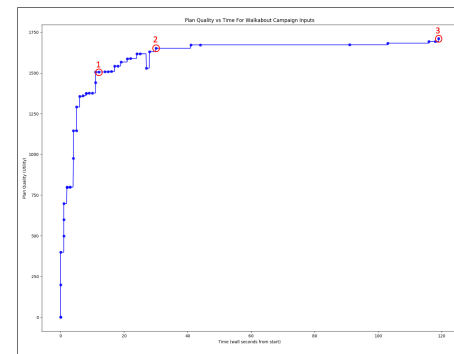
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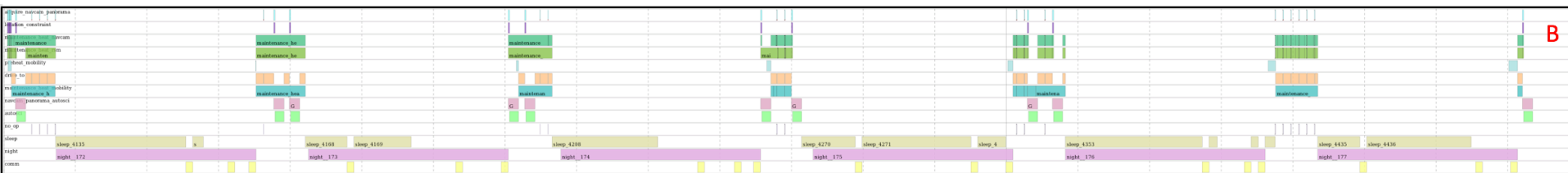
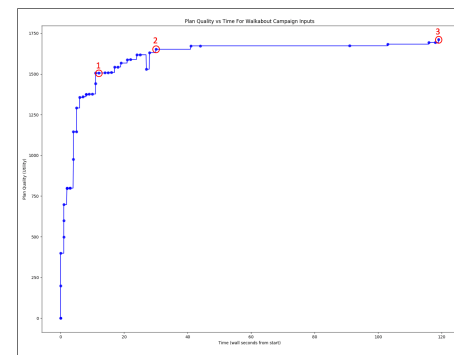
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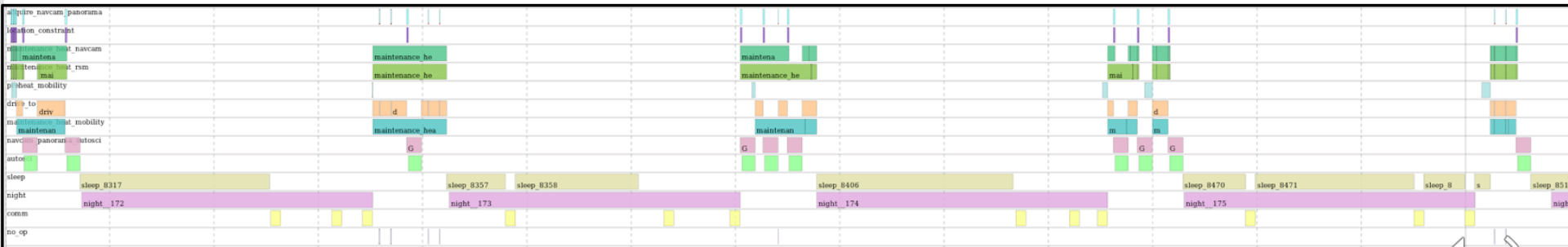
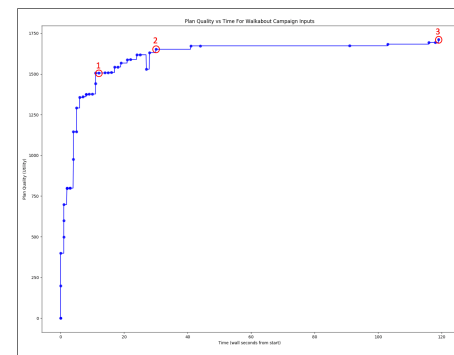
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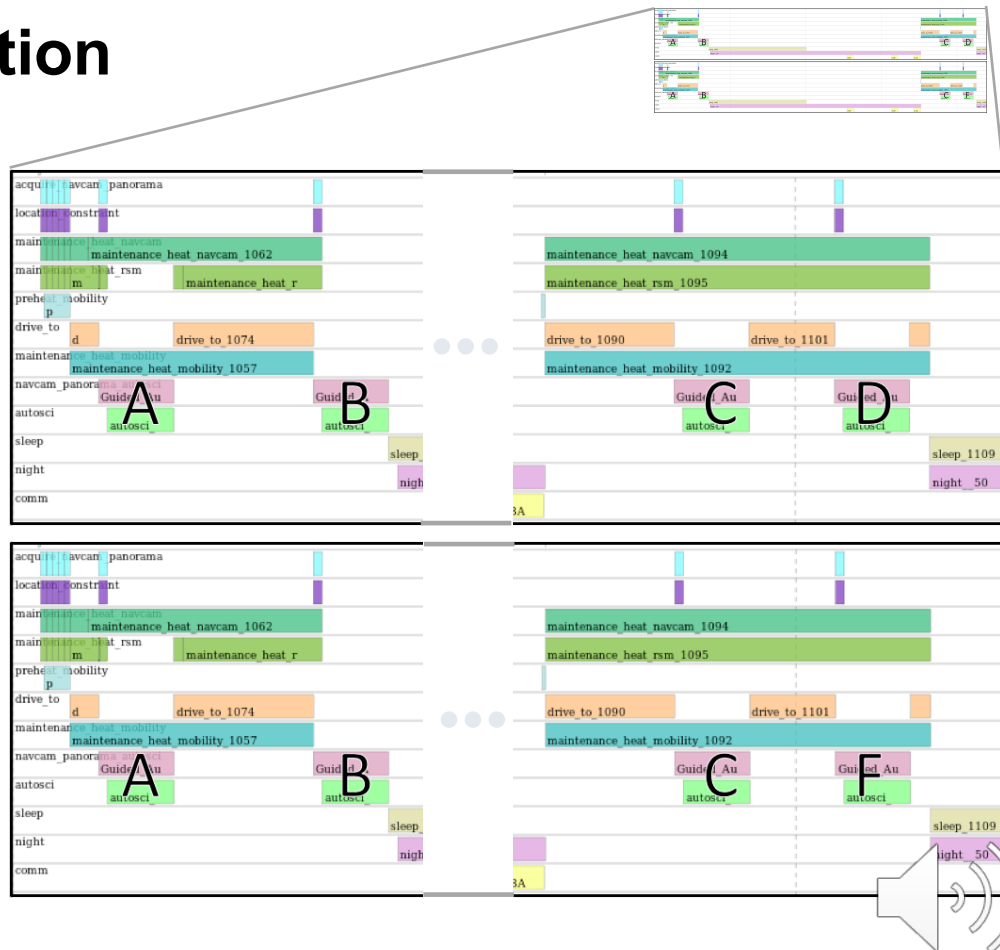




# Onboard Planning Evaluation

- Higher-utility goals given priority when resources are limited

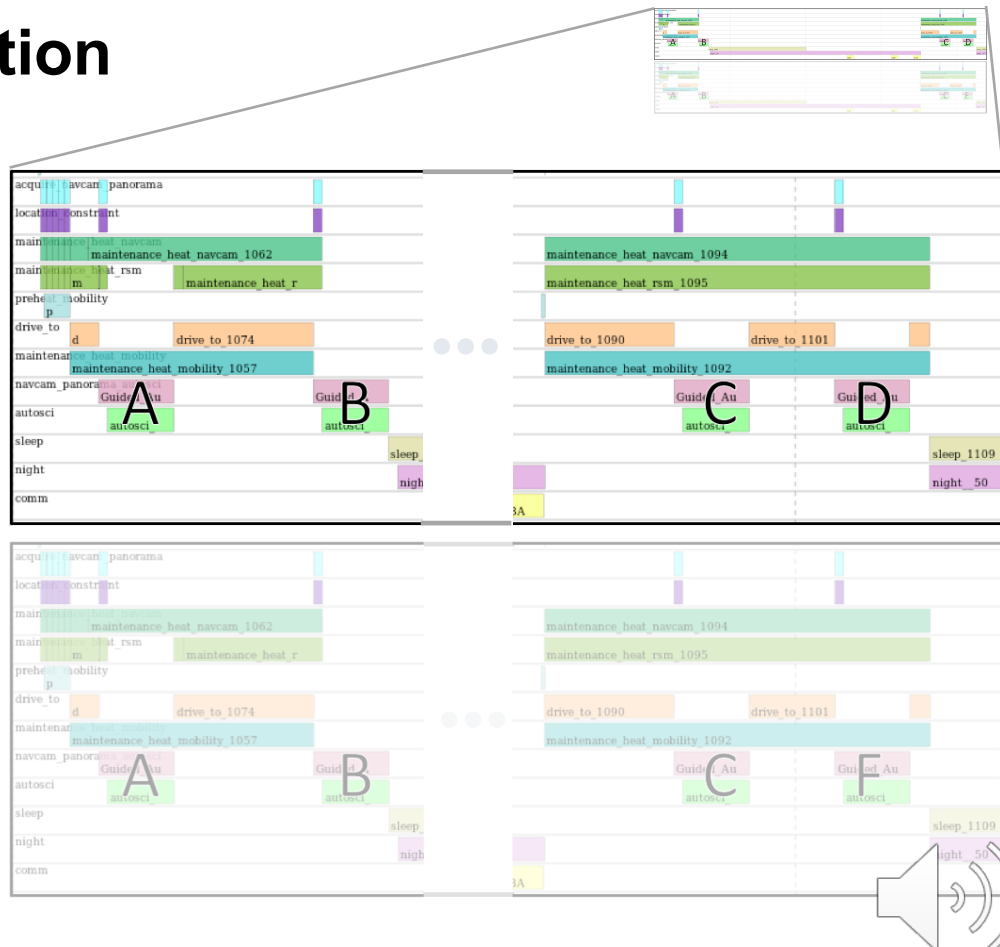
| Label | Target Name          | Target Utility |
|-------|----------------------|----------------|
| A     | Zoot                 | 100            |
| B     | Sweetums             | 200            |
| C     | Fozzie               | 100            |
| D     | Janice               | 100            |
| E     | Animal               | 100            |
| F     | DrJulius Strangeport | 200            |




# Onboard Planning Evaluation

- Higher-utility goals given priority when resources are limited

| Label | Target Name             | Target Utility |
|-------|-------------------------|----------------|
| A     | Zoot                    | 100            |
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| E     | Animal                  | 100            |
| F     | DrJulius<br>Strangeport | 200            |



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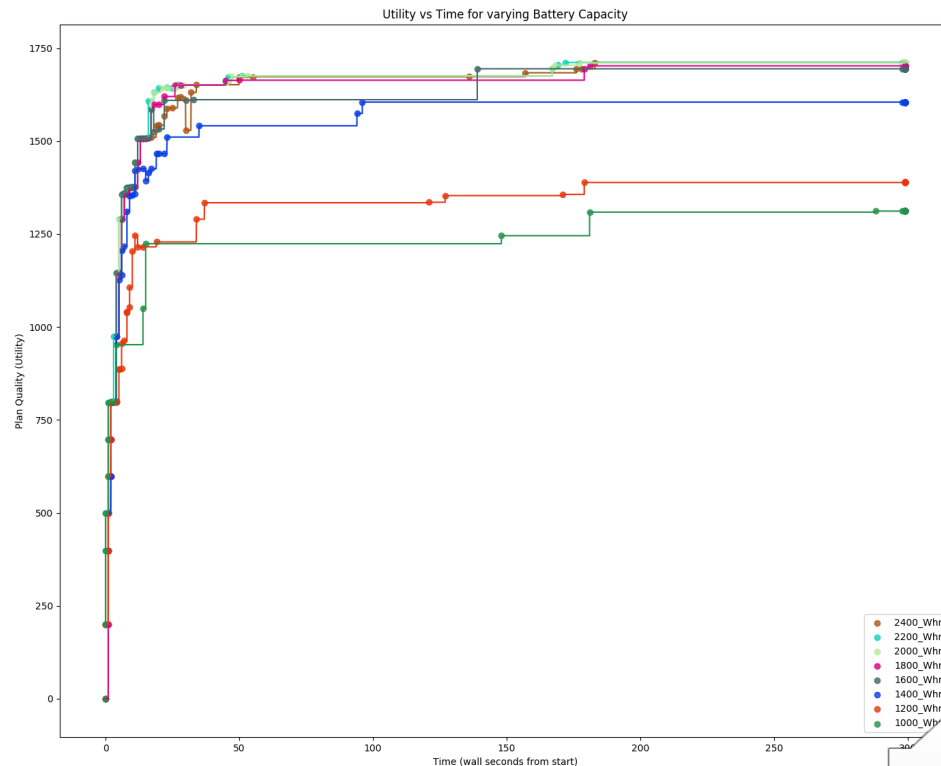


# Onboard Planning Evaluation

## Constraints

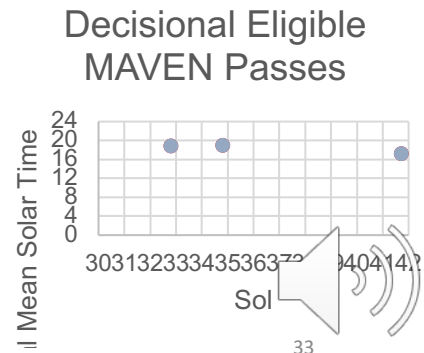
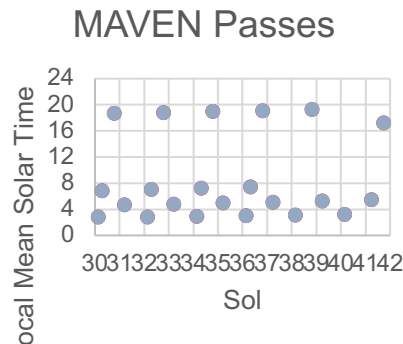
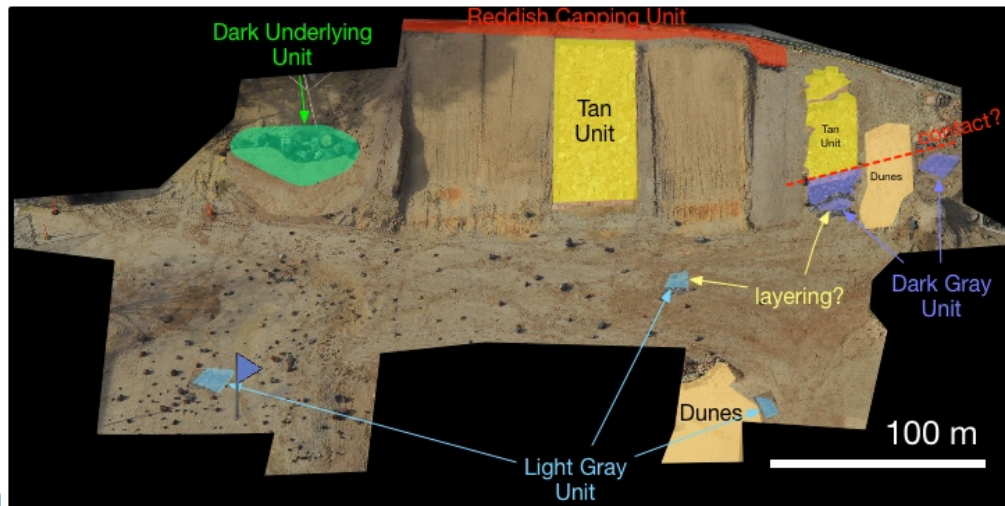
- Able to produce productive plans in when energy resources are tightly constrained

| Battery Capacity (Whr) | # Goals Achieved |
|------------------------|------------------|
| 1000                   | 5                |
| 1200                   | 7                |
| 1400                   | 9                |
| 1600                   | 10               |
| 1800                   | 10               |
| 2000                   | 10               |
| 2200                   | 10               |
| 2400                   | 10               |



# Evaluation: Mars Yard Walkabout

- Objective:
  - Evaluate ability to enable high productivity with limited communication
- Methodology
  - Walkabout campaign using SRR
    - Create geological scenes in Mars Yard
    - Use Maven-like comm windows
  - MSL scientists conducted campaign
    - Diana Blaney, Abigail Fraeman, Vivian Sun
    - 7 sols to complete walkabout with 3 uplink opportunities
  - Compared SRR performance with projected MSL performance



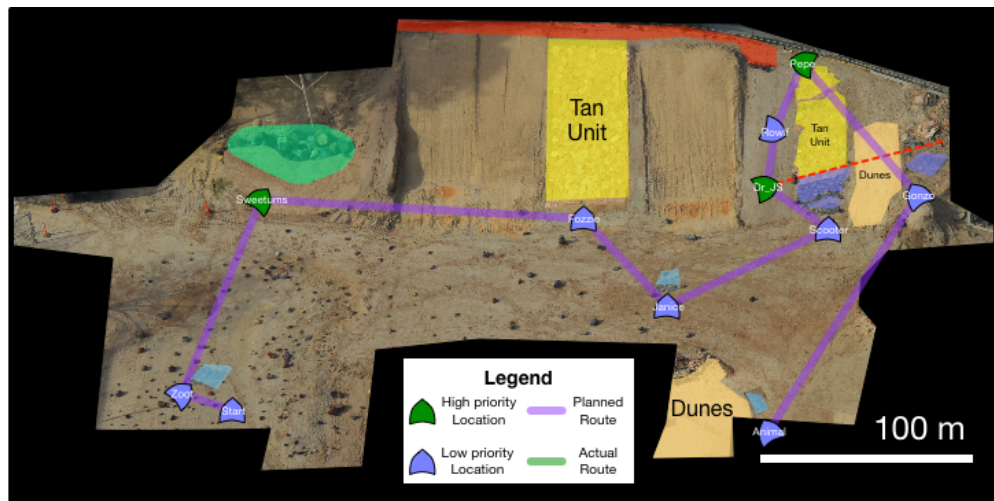
# Scientist Objectives and Initial Plan

| Location            | Detector           | Num Follow-Ups Min | Num Follow-ups Max | Priority |
|---------------------|--------------------|--------------------|--------------------|----------|
| Zoot                | Light Gray Outcrop | 2                  | 4                  | High     |
| Zoot                | Layering           | 3                  | 4                  | Normal   |
| Zoot                | Dark Gray Outcrop  | 2                  | 4                  | Normal   |
| Sweetums            | Dark Gray Outcrop  | 2                  | 4                  | High     |
| Sweetums            | Dark Rock          | 2                  | 4                  | High     |
| Sweetums            | Contact (Dark/Tan) | 2                  | 4                  | Normal   |
| Fozzie              | Tan Outcrop        | 2                  | 3                  | Normal   |
| Fozzie              | Layering           | 2                  | 4                  | High     |
| Fozzie              | Contact (Dark/Tan) | 2                  | 3                  | Normal   |
| Fozzie              | Reddish Rock       | 1                  | 2                  | Normal   |
| Janice              | Light Gray Outcrop | 2                  | 4                  | High     |
| Janice              | Layering           | 3                  | 4                  | Normal   |
| Janice              | Dark Gray Outcrop  | 2                  | 4                  | Normal   |
| Janice              | Contact (Dark/Tan) | 2                  | 4                  | High     |
| DrJuliasStrangeport | Layering           | 2                  | 4                  | High     |
| DrJuliasStrangeport | Dark Gray Outcrop  | 1                  | 2                  | Normal   |
| DrJuliasStrangeport | Tan Outcrop        | 1                  | 2                  | Normal   |

| Location | Detector           | Num Follow-Ups Min | Num Follow-ups Max | Priority |
|----------|--------------------|--------------------|--------------------|----------|
| Rowlf    | Layering           | 3                  | 6                  | Normal   |
| Rowlf    | Tan Outcrop        | 3                  | 6                  | Normal   |
| Pepe     | Reddish Rock       | 2                  | 4                  | Normal   |
| Pepe     | Contact (Dark/Tan) | 2                  | 4                  | High     |
| Pepe     | Layering           | 2                  | 4                  | Normal   |
| Gonzo    | Sand               | 2                  | 3                  | High     |
| Gonzo    | Contact (Dark/Tan) | 2                  | 4                  | High     |
| Gonzo    | Layering           | 2                  | 3                  | Normal   |
| Gonzo    | Dark Gray Outcrop  | 2                  | 2                  | Normal   |
| Gonzo    | Dark Gray Outcrop  | 2                  | 4                  | High     |
| Scooter  | Layering           | 1                  | 2                  | Normal   |
| Scooter  | Contact (Dark/Tan) | 1                  | 2                  | Normal   |
| Scooter  | Dark Rock          | 2                  | 4                  | Normal   |
| Scooter  | Light Gray Outcrop | 2                  | 4                  | High     |
| Animal   | Layering           | 3                  | 4                  | Normal   |
| Animal   | Dark Gray Outcrop  | 2                  | 4                  | Normal   |



# System Evaluation: Mars Yard Walkabout Campaign Results

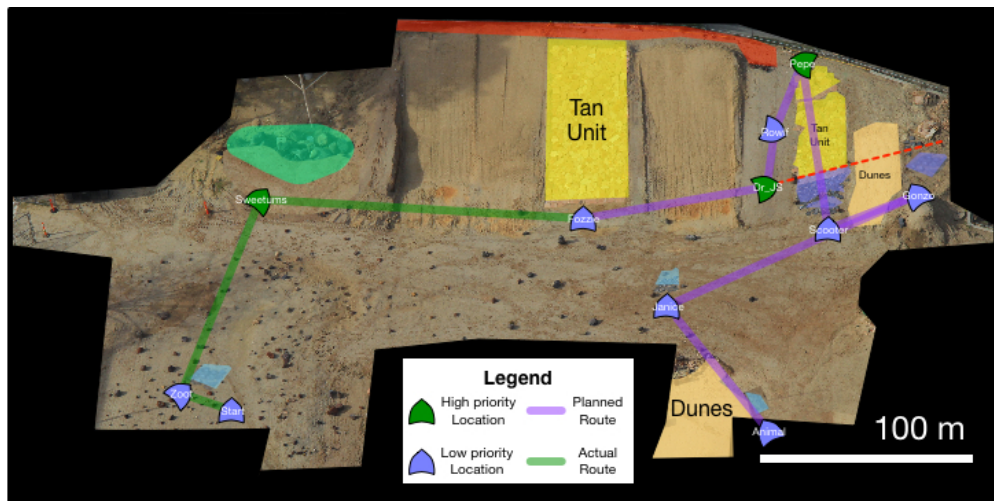


Sol Path from Initial Plan

|        |   |           |
|--------|---|-----------|
| Sat 31 | Drive + Post Drive Imagery  | Assessing |
| Sun 32 | Untargeted Remote Sensing   |           |
| Mon 33 | Targeted Science, Drive to Zoot, Survey Zoot, Drive toward Sweetums                         | Plan 1    |
| Tue 34 | Arrive at Sweetums, Survey Sweetums, Drive to Fozzie  |           |
| Wed 35 | Survey Fozzie, Drive to Janice, Survey Janice, Drive toward Scooter                         | Plan 2    |
| Thr 36 | Arrive at Scooter, Survey Scooter, Drive to DrJS, Survey DrJS, Drive to Rowlf, Survey Rowlf |           |
| Fri 37 | Drive to Pepe, Survey Pepe, Drive to Gonzo, Survey Gonzo, Drive toward Animal               |           |
| Sat 38 | Survey Animal   | Plan 3    |
| Sun 39 | Unused  |           |



# System Evaluation: Mars Yard Walkabout Campaign Results



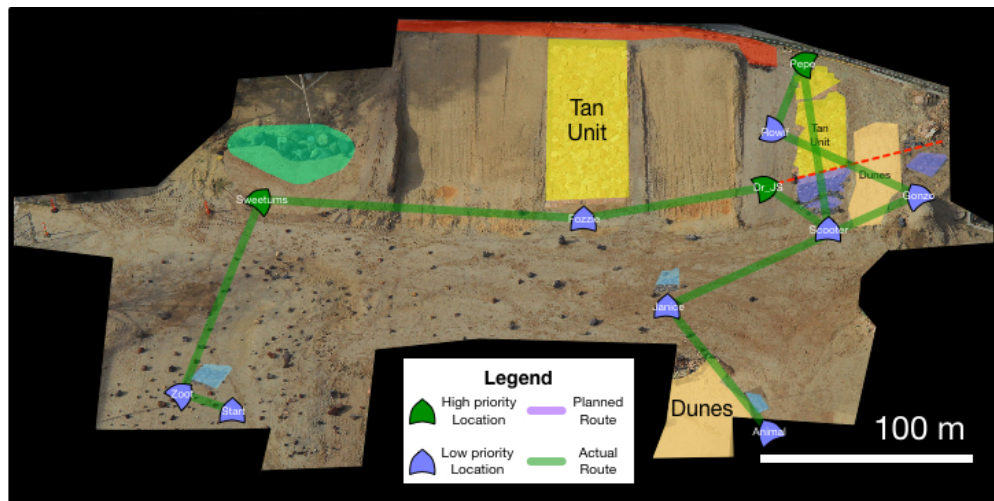
Sol Path after Plan 1 Execution

|        |   |                   |
|--------|---|-------------------|
| Sat 31 | Drive + Post Drive Imagery  |                   |
| Sun 32 | Untargeted Remote Sensing   |                   |
| Mon 33 | Targeted Science, Drive to Zoot, Survey Zoot, Drive to Sweetums             | Plan 1: Assessing |
| Tue 34 | Survey Sweetums, Drive to Fozzie, Survey Fozzie                             |                   |
| Wed 35 | Drive to DrJS, Survey DrJS, Drive to Rowlf, Survey Rowlf, Drive to Pepe     | Plan 2            |
| Thr 36 | Survey Pepe, Drive to Scooter, Survey Scooter, Drive to Gonzo, Survey Gonzo |                   |
| Fri 37 | Drive Janice, Survey Janice, Drive to Animal, Survey Animal                 |                   |
| Sat 38 | Unused  | Plan 3            |
| Sun 39 | Unused  |                   |





# System Evaluation: Mars Yard Walkabout Campaign Results



Sol Path after Plan 2 Execution

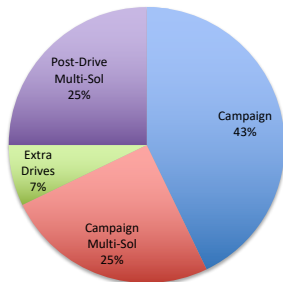
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| Mon 33 | Targeted Science, Drive to Zoot, Survey Zoot, Drive to Sweetums            | Plan 1            |
| Tue 34 | Survey Sweetums, Drive to Fozzie, Survey Fozzie                            |                   |
| Wed 35 | Drive to DrJS, Survey DrJS, Drive to Scooter, Survey Scooter               | Plan 2: Assessing |
| Thr 36 | Drive to Pepe, Survey Pepe, Drive to Rowlf, Survey Rowlf                   |                   |
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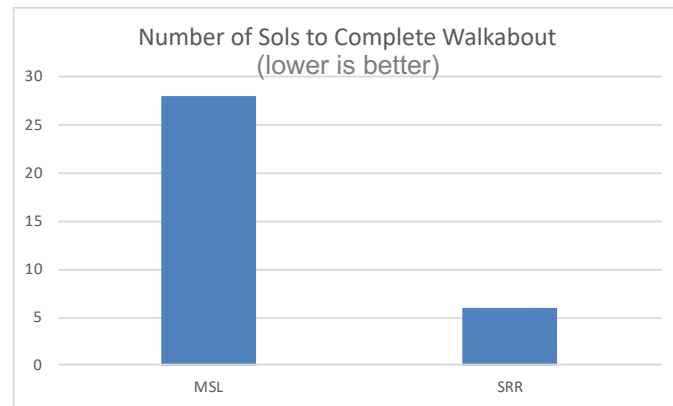
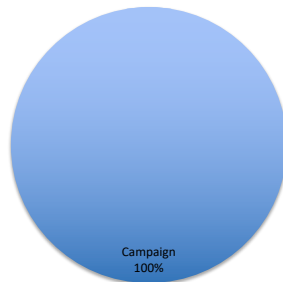
# System Evaluation: Mars Yard Walkabout Campaign

## Results

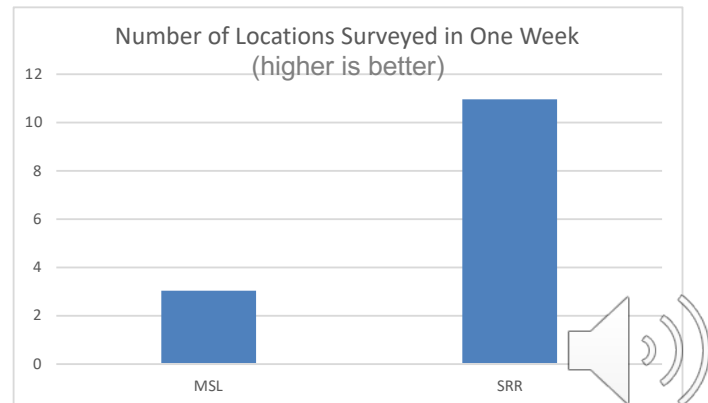
MSL



SRR



- SRR productivity vs. MSL
  - **47% increase in number of productive sols**
    - SRR able to make full use of every sol
  - **80% (4.7x) reduction in number of sols** to survey all locations
  - **267% (3.7x) increase in locations surveyed** in one week

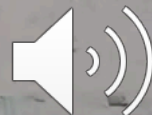


# Geometric Hazards

Rover Start

Sand Hazard

Science Targets



# Self-Reliant Rover Team

- Dan Gaines (PI)
- Ryan Mackey (Co-I)
- Gregg Rabideau (Co-I)
- Ashwin Vasavada (Co-I)
- Bob Anderson
- Ali Agha
- Gary Doran
- Chet Joswig
- Heather Justice
- Ksenia Kolcio (Okean)
- Mike Paton
- Brandon Rothrock
- Joe Russino
- Jacek Sawoniewicz
- Steve Schaffer
- Vincent Wong
- Kathryn Yu

## Advisors

- Issa Nesnas (Initiative Lead)
- Magdy Bareh
- Lorraine Fesq
- Mark Maimone





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